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Valuable use-cases towards a generic model of geo-station welding

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Abstract

To ensure a robust mass production, the automotive industry relies on computer aided tolerancing to guarantee the dimensional quality of the vehicles' body-in-white. One of the challenges for computer aided tolerancing is the accurate modelling of the positioning for joining processes in the body-in-white production. The research work presented in this paper analyses three use-cases, on which different approaches of modelling of the so-called geo-stations are investigated, aiming at improving the deviation prediction based on the geo-station modelling. The examples show that the measurement values are met most accurately, if the positioning processes of the geo-station are taken into account as the dominant impact factor in the simulation.

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Keywords: Body-in-white; geowelding; dimensional accuracy

1. Problem statement and motivation

Industrial production implies interchangeability between the single components a product is made of. Independent of the batch, the date of production etc. of the single components, the resulting assembly must feature the desired properties. The manufacturing deviations of the components must only affect the dimensional quality within narrow, pre-defined limits. To define those boundary values tolerance simulations are carried out. As with every simulation the modelling of the determining factors is an essential contribution to obtain reasonable results.

This paper assesses the modelling of geometrical welding (geowelding) which defines the dimensional accuracy within the joining process, so-called geo-welding. In these stations the components to be joined are clamped in a precisely defined position to each other, compare [1]. As the single components may have deviations within the permitted limits the geometrical configuration could oppose the positioning set up by the geo-station, as schematically shown in Fig. 1. In this example both parts have too small dimensions in the X-direction. The grey bars represent the pins which position the parts in the X-direction. As the parts are positioned according to their required geometrical design form the non-ideal shape causes a gap between the joining flanges, marked by the weld nugget symbol.

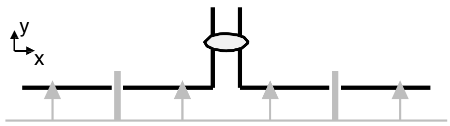

Fig. 1. inequality of components' geometry and positioning set up by geo-station.

In the described situation there are three options to overcome the occurring gap. a) the clamping by the geo-station is too loose, so that both components move towards each other if the welding gun presses the two flanges together, b) both geometries become holistically deformed, which most likely will be an elastic deformation, resulting in a spring back behavior if the clamps are opened again, or c) there will be an only local plastic deformation of the flange area. Option a)

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indicates a low impact of the geo-station's positioning and a dominating influence of the components' geometric character. Options b) and c) on the other hand occur, if the dimensional positioning of the geo-station is decisive.

This research work compares different computer aided tolerancing modelling approaches to measurement data. The geowelding of selected use-cases is modelled in different ways, according to the mentioned options. The resulting data is contrasted with inline measurement data of the respective use-case.

2. Research boundary conditions and resources

2.1. Analyses performed in the body-in-white environment

Industrial production is installed if a high quantity of goods is manufactured. The surroundings described at the beginning of Chapter 1 condition a statistical analysis to be carried out, if any dimensional quality of a vehicle's body-in-white is assessed. Since mass production vehicles are produced several hundred thousand times over their life cycle, investigating a small sample size is not sufficient. This is why the use-cases have to feature inline measurement technology which enables to access a large size of measurements. Also the position of the measurement points is checked when choosing the use-cases. Since cycle time is always closely monitored, there are only a limited number of measurement points available.

Moreover only a little number of single components have to be involved in the joining process. This way, the non-ideal shape of the single components and of the assemblies can be compared more easily. Under consideration of the described criteria three use-cases are picked. The measurement data is statistically evaluated and the joining configuration is rebuilt with computer aided tolerancing software.

2.2. Employed technologies and tools

The computer aided dimensional analysis is carried out with the commercial software 3DCS by Dimensional Control Systems. Nevertheless the approaches presented here can also be implied with other software. As CAD data of the investigated parts is available, simulations easily can be set up by CATIA-integrated 3DCS. Thereby, the new approaches are compared to the conventional approach used in the industry. 3DCS uses the Monte Carlo-method to perform statistical simulations. 10000 runs are computed per approach, having each parameter scattering within its assigned statistical distribution pattern.

Tolerance analyses carried out with 3DCS focus on the statistical spread as evaluation criterion. Since unilateral tolerances and their technical needfulness are hard to asses, mean difference analyses are rarely performed with computer aided tolerancing simulations. This is the reason for focussing on the statistical spread in our work when analysing the use-cases.

The computations are carried out on the base of rigid body motions. As no elastic or plastic behaviour is regarded, the parts can only be clamped statistically determined. So if there are more than six datums which need to be taken into account, intermediation between fixtures is applied. There is no deviation behaviour mapped by finite element methods as the approaches should have the potential to be applied in practice. It is a main goal of this research work to keep the modelling approach simple enough to be performed with reasonable effort. There are finite element based methods, like the one Ungemach [2] introduced, which are improving the usability of finite element based deformation mapping. But still the effort to build up simulations which include deformation computation is very high compared to purely statistical simulations. Moreover the computation time is many times higher with finite element calculations included, as for each run there are new boundary conditions for the deformation evaluation.

3. Development of representative use-cases

To evaluate the measurement data of and to set up the simulation for the use-cases the following surrounding conditions have to be considered.

3.1. Reference System

All measurements in the automotive industry are based on the same reference system. This reference system has its origin in the middle of the front axle of the vehicle. The axis' directions are set up as follows:

- X-axis: backward direction with respect to the vehicle
- Y-axis: lateral direction pointing to the right side of the vehicle
- Z-axis: upward direction with respect to the vehicle

3.2. Clamped support approach

Six reference points have to be chosen to constrain the component, which will be simulated. As indicated above, then any part is positioned statically defined.

All reference points are found in the fixing and clamping concept. The jigs and fixtures of course do fasten the parts on more than six points, so six of them have to be chosen. If there are more fixtures relevant for the joining operation, the mentioned mediation has to be performed.

3.3. Positioning of the parts according to the 3-2-1 principle

In order to ensure the required proper positioning of all parts during the assembly process the geo-stations refer to the 3-2-1 principle. The same principle is also essential for the simulation, as the moves in the simulation to position the parts shall reflect reality as well as possible. According to this principle each component in the joining station is fixed by three planes to be positioned statically defined:

- Primary plane: 3 coordinates
- Secondary plane: 2 coordinates
- Tertiary plane: 1 coordinate

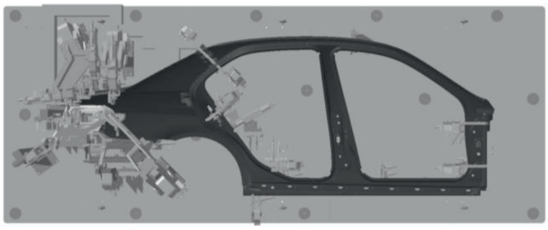

Fig. 2. geo-station while joining process.

As a result of using this procedure each of the six degrees of freedom is constrained. As indicated above, this would be enough to define the position of the part in space. But there are certain components in the manufacturing process which are too large or too flexible to be properly positioned by just six fixing elements, e.g. side wall panels (Fig. 2). This makes more clamps present than are theoretically required. These clamps are essential to prevent the parts from elastic deformation. On the other hand the rigid body approach, which is used in this research work, is restricted to just six fixtures for the simulation modelling. For the general procedure to set-up a move-based tolerance simulation with 3DCS see also [3].

Two kinds of effects are considered in the researched use-cases, so the deviation prediction can be improved. The first effect is the importance of geo-stations as a device to ensure dimensional quality. Geo-stations have to be taken as a much more important impact factor for the simulation modelling than it is currently the case in industrial applications. The second effect is the mediation between fixture points, if the position is decisively influenced by more clamping points than the 3-2-1 principle does allow for. This mediation will be carried out by means of dynamic points in 3DCS.

The side effect of this method is that the variation of dynamic points wanes which appears in the simulation results. The Monte Carlo method takes for each run the mean value of the two deviations which are supposed to be mediated. For two standard distributions which are mediated this results in the following equation:

$$\sigma_{med} = \frac{1}{n}\sqrt{\sum_{1}^{n}\sigma^2} \tag{1}$$

This shows that the standard deviation for the mediated point σ_{med} becomes smaller as more points are mediated. This may be a real phenomenon, as more clamps do centre a component more exact than fewer. However, this behaviour has to be researched separately from the geo-station influence to be able to clearly determine the impact factor of any change. So for the geo-station influence research this method should only be used where it is inevitable. This way it can be ruled out that the mediation is the reason for better results in general. The focus in this paper is on improving the deviation prediction based on the geo-station modelling. Therefore, no further detailed examination of the effects of the dynamic points was conducted.

4. Modelling approaches

In this chapter the selected use-cases for the modelling approach are introduced. The goal of the modelling approach is to improve deviation prediction for assemblies. For the following use-cases two different modelling approaches are employed. The first approach is in the manner of conventional industrial practice and the second features an improved mapping of the geo-station's influence.

4.1. Use-case 1: tail lamp assembly

This use-case deals with the outer sidewall panel and the tail lamp fixture. The evaluation criterion for this use-case is a measurement (M01) in the X-direction from the tail lamp fixture point to the reference measurement point in the front of the side wall outer, see Fig. 3. Since the joining area is located quite distant from the main X-direction fixation point of the sidewall, it is important to locate the measurement reference at this spot. If the main orientation and measurement references were separated the results would be implausible because of leverage effects.

Fig. 3. side wall panel and tail lamp fixture.

First of all the simulation is established according to the industry's conventional approach to obtain a reference for the new approaches. To find the right locators for the modified approach several versions are set up. In order to find the best solution it is necessary to carry out an iterative process with different reference points in the simulation modelling.

For the conventional approach the X- and Z-orientation of the sidewall is modelled by a hole slot combination. After the trial of several fixation points the same hole slot combination is used for the new approach without mediation. To take the several X-fixtures into account which influence the position of the parts, a third version applying mediation between points is set up. So of the sidewall and the lamp housing X-reference points are mediated. For this approach it is investigated which dynamic point would result in the most accurate result. It can be revealed that the location of the points to be mediated have a rather small impact. Only the mediation itself displays more accurate results independent of the location of the mediated points. Also the simulated deviation is decreasing for the dynamic points on both parts compared to only mediating on one part.

The modelling of the geo-station is modified by decreasing the assigned tolerance values of the hole pin combination, which are the decisive elements regarding the positioning in the X-direction. Measurement reports show that the pins of the geo-station exhibit a high level of geometric accuracy. Hereby it is important to note that the change of a different pin hole tolerance has a greater impact on the results than the change of a single dynamic point.

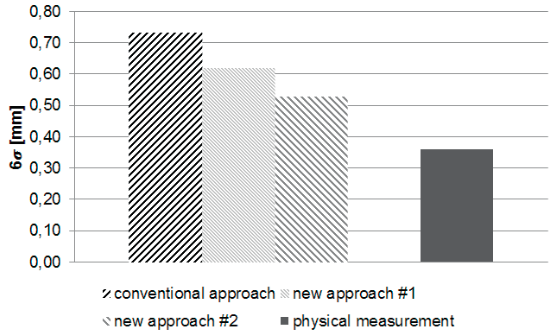

Fig. 4. sixfold standard deviation in X-direction of different approaches of use-case 1.

The final results for use-case 1 are displayed in Fig. 4. The conventional approach suggests a sixfold standard deviation which is about double the size of the actually occurring deviation, presented as physical measurement in the diagram. Applying the new approach #1, which improves the modelling of the geo-station, the simulation measurement shows smaller values, closer to the real measurement. Further improvement can be achieved by the mediation of X-fixation points. Though the new approaches display a considerable improvement compared to the conventional approach, the values still do not match the physical measurement. As use-case 1 contains the most flexible geometry of all discussed use-cases, this one is the hardest to be modelled with a rigid approach, which may explain why the simulation did improve, but still lacks of accuracy.

4.2. Use-case 2: front longitudinal beam I

This use-case deals with the assembly of the front longitudinal beam to the side wall panel as displayed in Fig. 5. The first step is as before to choose the right fixation points for the move. The modelling for the inner sidewall is set up just once for all approaches. As the main measurement and fixation point in the X- and Z-direction is located very close to the joining area, variation of modelling in this area is not constructive. For the evaluated measurements it is more important how the front longitudinal beam is modelled in the simulation than the sidewall.

Fig. 5. front longitudinal beam and sidewall.

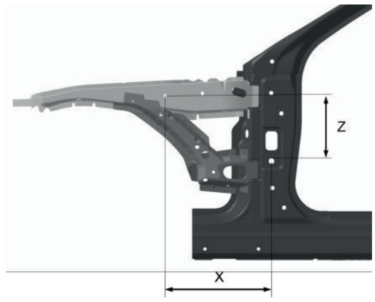

Fig. 6. X & Z measurement.

The modelling for the conventional approach of the longitudinal beam takes into account that the surrounding parts, e.g. the lower beam seen below the longitudinal beam in Fig. 6, have a link to the part. So the X- and Y-tolerances of the interlinking part have an influence on the resulting positioning tolerance of the longitudinal beam itself. This has a direct effect on the X- and Z- measurements.

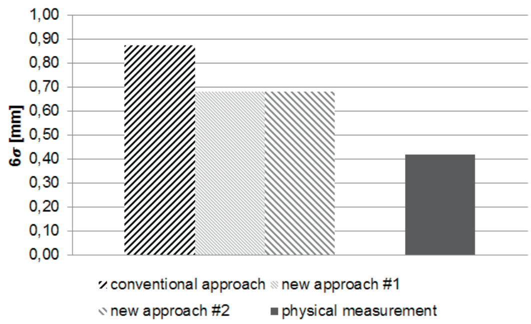

Fig. 7. sixfold standard deviation in X-direction of different approaches of use-case 2.

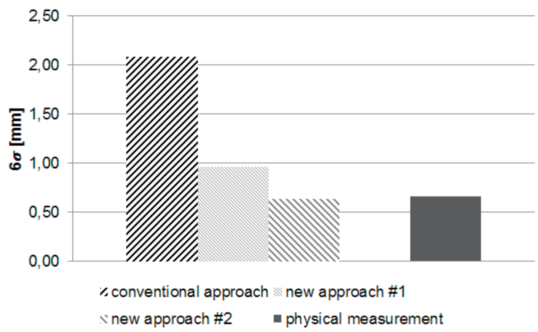

Fig. 8. sixfold standard deviation in Z-direction of different approaches of use-case 2.

With the new approach the longitudinal beam is installed directly into the geo-stations without consideration of the dependencies of the other parts. Hence the longitudinal beam is referring only to the geo-station regarding its X- and Z-positioning. Here the idea of the positioning of the parts only by the geo-station is implemented continuously and in clear contrast to the conventional approach. Moreover further fixture combinations for the longitudinal beam are researched; regarding which geo-station fixtures have to be considered. Of course also the pin hole tolerance is modified likewise use-case 1.

Again, Figures 7 and 8 also present an approach with mediated fixation points in Y- and Z-direction, new approach #2. Fig. 7, displaying the statistical spread in X-direction, shows that the new approaches meet considerably closer than the conventional approach. Since the X-positioning of the longitudinal beam is only achieved by the pin of the geo-station, a mediation in X-direction makes no sense. This is why there is no difference between the new approaches #1 and #2. The difference is only seen in Fig. 8, since this diagram shows the deviations in Z-direction. As new approach #2 does mediate in Z-direction, a difference between #1 and #2 is seen here. In general Fig. 8 displays very accurate results for the new approaches. Like in the experiment before the combination of dynamic points and adjusted geo-station representation conducts the best results.

4.3. Use-case 3: front longitudinal beam II

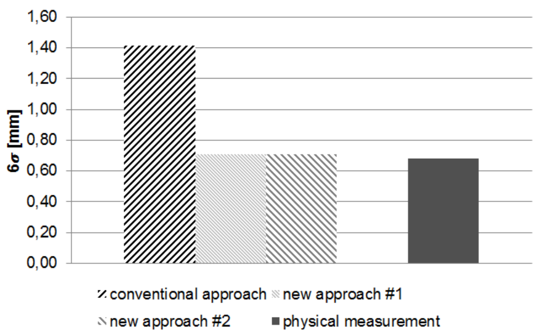

Fig. 9. sixfold standard deviation in X-direction of different approaches of use-case 3.

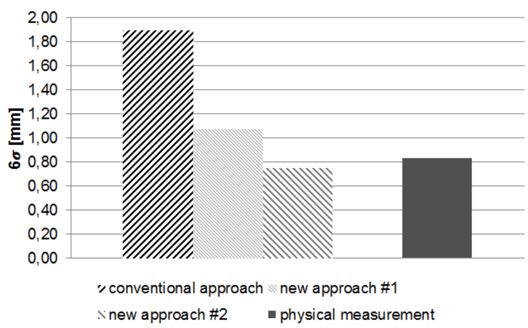

Fig. 10. sixfold standard deviation in Z-direction of different approaches of use-case 3.

The last use-case is similar to use-case 2. The same components are analysed on a different vehicle model. Equally to use-case 2 there is only one modelling approach for the inner sidewall, the variation study is performed only on the longitudinal and the lower beam. For both the conventional and the new approaches the longitudinal beam is installed into the geo-station under similar conditions like in use-case 2.

Like use-case 2, also use-case 3 shows an improvement if the parts to be joined are only positioned by the geo-station and not by contact conditions to each other. In general both new approaches meet the physical measurement values very well. Fig. 9 shows the measurement evaluation in X-direction while Fig. 10 exhibits the results in Z-direction. Likewise to use-case 2 the improvement by the mediation impacts only the Z-dimension, since there is no mediation performed for the X-direction.

5. Discussion and results

This research work compares the industry's conventional modelling approach to modified approaches which admit a larger dimensional impact to the positioning influence of the geo-stations. For use-case 1 the achieved improvements are quite small. Already with the conventional approach the components are mainly positioned with the geo-station in the simulation. So only the modelling of the geo-station's accuracy was modified, which did not improve the results to the large extent as can be achieved with use-cases 2 and 3. The geometrical configuration of use-case 1 makes it difficult to be properly modelled by a rigid approach.

Much larger improvements can be put into effects with use-cases 2 and 3. Here the geo-station oriented alignment of the components to be joined exhibits much better results than the conventional approach, according to which a lot of contact conditions between components have to be taken into account. As measurement values show that assemblies created by geo-stations can exceed the single parts' dimensional quality, the new geo-station focused approaches meet the measurement values much better.

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